

# **High Frequency Propagation and Scattering in Coastal Waters**

David M. Farmer  
Graduate School of Oceanography (educational)  
University of Rhode Island  
Narragansett, RI 02882  
Phone: (401) 874-6222 fax (401) 874-6889 email: [dfarmer@gso.uri.edu](mailto:dfarmer@gso.uri.edu)

Svein Vagle  
Institute of Ocean Sciences  
Fisheries and Oceans Canada (foreign government)  
PO Box 6000, Sidney, B.C., Canada V8L 4B2  
phone: (250) 363-6339 fax: (250) 363-6798 email: [vagles@dfo-mpo.gc.ca](mailto:vagles@dfo-mpo.gc.ca)

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## **LONG-TERM GOALS**

The long term goals of this study are to develop a firm physical and oceanographic basis for modeling propagation relevant to acoustical communications in the presence of bubbles. We identify the link between the acoustic modeling and the modeling of the hydrodynamics and bubble distribution as a key to a robust, physics based understanding of propagation in these environments. Our goal is to acquire appropriate measurements and use the data sets to test appropriate propagation models.

## **OBJECTIVES**

Our goals are (1) to establish the link between wave breaking, subsurface bubble distribution and the ambient noise field; (2) implement a hydrodynamic model of bubble movement and evolution and test this model against observations of wavefield and whitecap distribution, bubble injection, turbulence, dissolution and Langmuir circulation; (3) combine the hydrodynamic bubble model with an acoustic scattering and propagation model.

## **APPROACH**

Our approach has included implementation of high frequency propagation systems in a variety of environments relevant to acoustic communications including the surf zone and surf generated rip currents, in bubble clouds generated by breaking waves in continental shelf and deeper waters, and bubble clouds laid down in ship wakes. In addition to the field studies we are developing acoustic propagation and scattering models applicable to these environments in which the acoustic models are coupled to hydrodynamic models of the bubble distribution. For propagation in the surf zone our analysis includes scattering from bubbles in a wedge shaped environment. Propagation in bubble clouds advected by rip currents is modeled using a bubble size distribution that evolves under the combined influence of bottom generated turbulence, buoyancy effects and bubble dissolution. Our approach to propagation in turbulent wakes has involved propagation along paths within the wake, together with *in situ* bubble measurements, so as to test in a controlled environment the concept of propagation with a waveguide generated by the entrained bubbles. Our approach to high frequency

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propagation near the ocean surface at high wind speeds includes observational and model analysis of the relative contribution of specular and volume scatter.

Key individuals participating in the work:

D M Farmer is an acoustical oceanographer responsible for project design and analysis

S Vagle is an acoustical oceanographer responsible for implementation of acoustical systems and analysis

G Deane is an acoustical oceanographer at Scripps who is collaborating in the research including both field studies and acoustic analysis

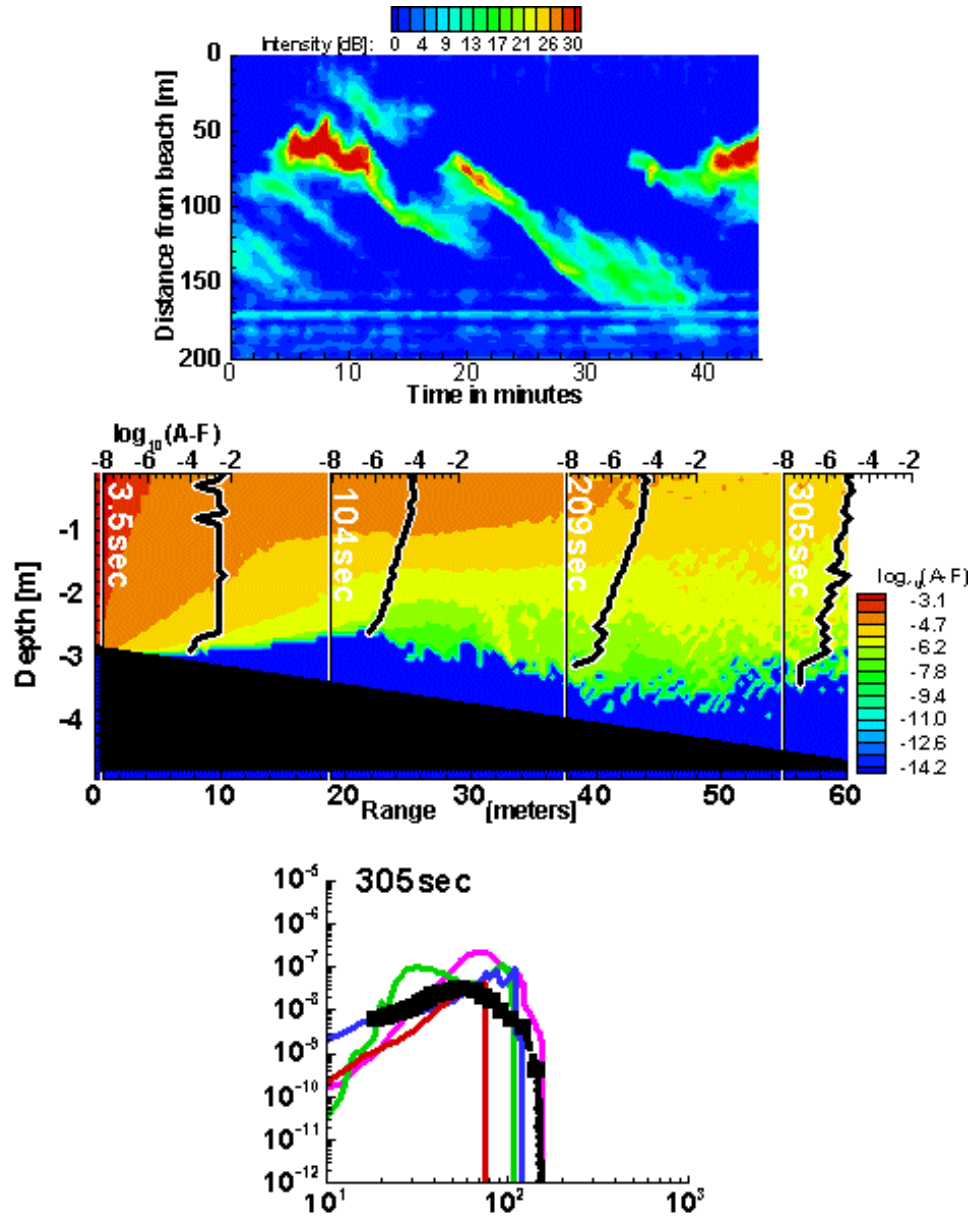
D Stokes is an interdisciplinary ocean scientist at Scripps who is collaborating in the research including field studies and specialized instrumentation

## **WORK COMPLETED**

1. Analysis of acoustical effects in the surf zone and in rip currents has been completed for the case of high frequency propagation through, and back scattering from, bubble clouds generated by breaking waves.
2. Analysis of the masking effect of bubble clouds on high frequency scattering from the surface at higher sea states has been completed, in particular analyzing the relative contribution of volume scatter to specular scatter as a function wind speed.
3. Analysis has been completed of high frequency acoustic propagation in bubble clouds artificially generated in the wake of a small vessel.

## **RESULTS**

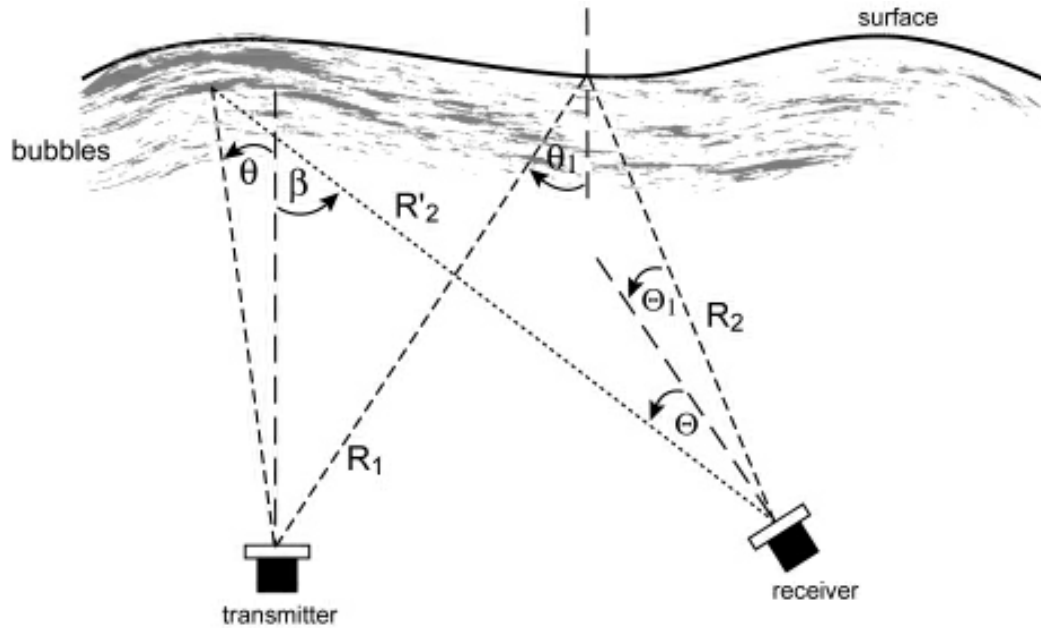
Observations of scattering and propagation effects in the surf zone identify the effects of an acoustical barrier formed by bubbles as it is advected and transformed under the influence of injection, advection by rip currents, buoyancy effects, turbulent redistribution due to wave boundary layer generated turbulence and the effects of gas dissolution. Farmer, Deane & Vagle (2001) model the initial recovery following bubble injection and show that buoyancy sorting dominates the initial stages and can explain the quite rapid opening of a 12kHz propagation channel compared to a more slowly clearing channel at higher frequencies. Rip currents provide more time for bubble cloud evolution, but the overall behavior is consistent with bottom generated turbulence that can maintain the bubbles in the water column for many minutes (Vagle, Farmer & Deane, 2001). Observed bubble size distributions reveal an almost complete lack of larger bubbles in the more extended measurements of bubble clouds advected by rip currents, which is also consistent with predictions (Figure 1).



**Figure 1.** *Upper Panel: This shows a 45 minute time series acoustic image acquired with a sonar looking inshore towards the surf zone and illustrates the offshore advection of bubble clouds due to rip currents. Middle Panel: The color contour image shows the logarithm of air-fraction as a function of depth and distance offshore that is predicted with our model as the bubbles field evolves from its source in the surf. Lower Panel: Bubble size distribution predicted in the far-field, offshore of the surf zone (colored lines) and the model prediction. The general shape is well predicted by the model.*

Measurements of acoustical scatter at high sea states in the North Sea using a bistatic sonar on the sea floor (40m deep) show that a model using characteristic bubble size and depth distributions explains the relative contribution of specular scattering from the sea surface to the contribution from bubbles

(Farmer, Ding, Booth & Lohmann, 2001). At steep angles of incidence, the specular scatter at 100kHz is lost to volume scatter above wind speeds of about  $14\text{ms}^{-1}$ . Above this wind speed the surface is essentially masked. Turbulence appears to be a minor contributor to spectral broadening at this frequency.



**Figure 2.** *The relative contribution of specular scatter from the sea surface (dashed line intersecting surface) to volume scatter from bubble clouds just beneath the surface at high sea states has been investigated with measurements from a bistatic sonar mounted on the sea floor. Model calculations showing the transition in dominant scatter have proved consistent with observations for the frequency and angles of incidence used in the study.*

Observations of characteristic bubble sizes beneath open ocean breaking waves which are needed for accurate propagation and scattering models, acquired during a deployment in the Gulf of Mexico, show both the stability of distributions and the extent to which they follow predictions based on simple injection/buoyancy/dissolution models. In the dissolution regime, the volume scaled distribution satisfies a power law fitted slope of 1.7, with standard distribution of 0.3; the power law slope in the buoyancy dominated regime tends to be more scattered (slope  $-2.9$ , standard deviation 0.8), reflecting the greater sensitivity to the initial injection process.

Our observations in collaboration with G B Deane have led to a deeper understanding of sonar performance in the surf zone (Deane, Vagle & Farmer, 2001), including the special effects associated with the wedge shaped scattering volume.

## IMPACT/APPLICATIONS

Modeling and analysis of bubble distributions in the surf and near shore environments are providing a basis for inclusion in propagation predictions. The verification of hydrodynamic aspects, including

bubble hydrodynamics, turbulent redistribution and related effects are essential for adequate propagation models, especially given the sensitivity of bubble scattering to acoustical frequency. Bistatic surface scattering measurements and modeling is providing a first step towards the verification of bubble induced effects in open ocean environments. Such preliminary findings will play a role in the design of forthcoming bubble-acoustic studies planned by the Ocean Acoustics Division. Our combined turbulence-buoyancy-dissolution-advection model is being incorporated in an operational model (SWAT) for inshore acoustical predictions by Gary Sammelmann (Panama City).

The observations of Doppler performance in the surf zone allow improved prediction of performance of Doppler sonars as well as providing insight on aspects such as Doppler spread, relevant to acoustic communication performance.

## **RELATED PROJECTS**

This work is scientifically linked to the Surf Zone Acoustic Transmission Experiment. The work is naturally linked to the planned bubble-acoustics experiment, for which it serves as an appropriate guide in experimental design.

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